Program Objectives

Systems Improvements in Home Construction

- **Increase Energy Efficiency**
  - **Increase Affordability**
  - **Improve Comfort**
- **Reduce Resource Use**
  - **Increase Durability**
- **Improve Health and Safety**

Advantage to Builder

- Reduces callback and warranty problems
- Improves building performance while reducing construction costs
- Predictable lower utility bills allow innovative marketing & financing
- Gives builder a competitive advantage without increased cost

Key Concepts

- Cost Trade-Offs
  - Improve Building Envelope (+)
  - Downsize Mechanical Equipment (-)

- Total Cost =
- Remains the Same or Costs Less

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March 1999

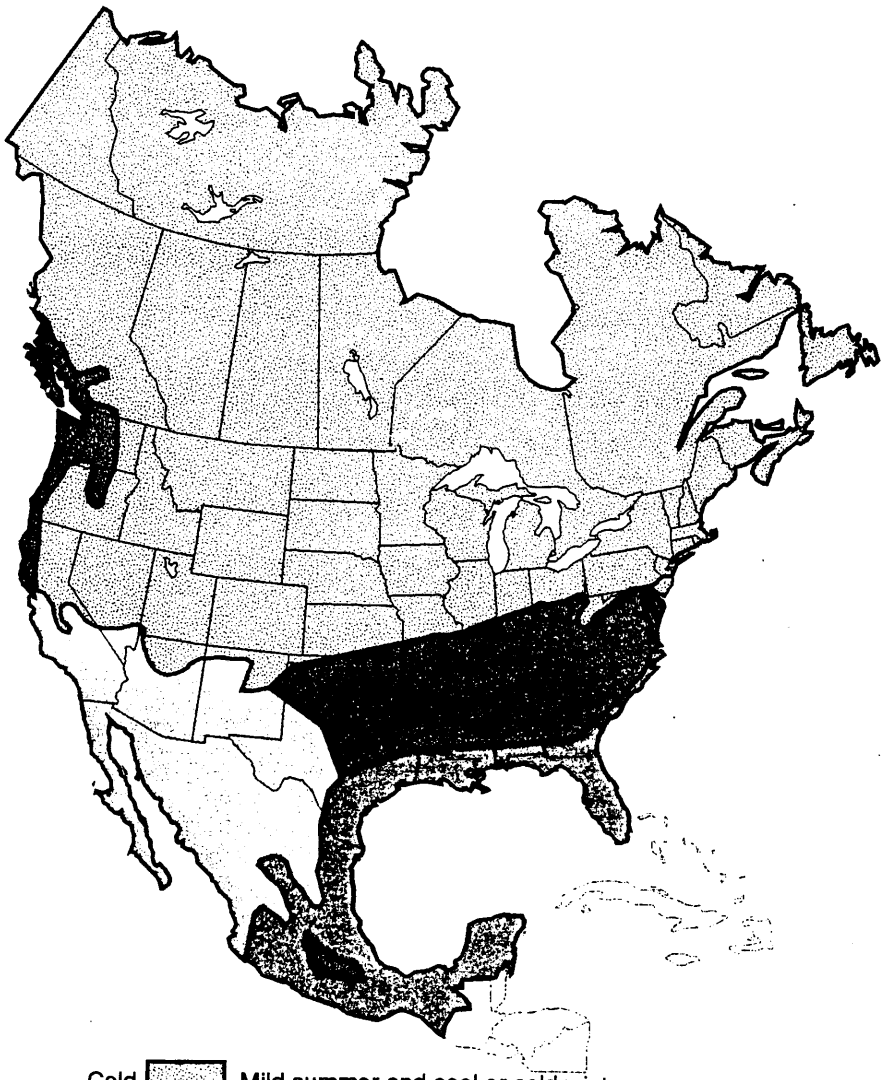
Building Science Consortium

Totals Building Science Consortium

Homes Started or Completed	497	Energy Saved	25,835 Mbtu
Homes Tested	145	C emissions saved	1,278,887 lbs
Energy Star Homes	230	SO_2 emissions saved	6,057 lbs
Total Build-Out	3,308	NO_x emissions saved	6,895 lbs

Pressure Equalized Rain Screen		Over 60"
Rain Screen		50" - 60"
Drainage Plane		30" - 50"
Face Seal		Under 30"

Annual Rainfall Map



Cold — Mild summer and cool or cold winter

Mixed-Humid — Hot summer and cool winter (more than 20 inches/ 50 cm annual precipitation)

Hot-Humid — Hot summer and mild winter

Hot-Dry Mixed-Dry — Hot summer and mild or cool winter (under 20 inches/ 50 cm annual precipitation)

Hot	=	above 68°F/20°C
Mild	=	50°F/10°C to 68°F/20°C
Cool	=	32°F/0°C to 50°F/10°C
Cold	=	below 32°F/0°C

Climate Zones

Based on Herbertson's Thermal Regions, a modified Koppen classification, the ASHRAE definition of hot, humid climates and average annual precipitation from the U.S. Department of Agriculture

Building Science Corporation
January, 1998

Cold Climate
Design and Cost Trade-offs

Advanced framing: 2x6s with R-20 instead of 2x4s with R-11	- $ 250
Insulating sheathing	+$ 300
No housewrap	- $ 300
High performance windows	+$ 300
Savings on duct system	- $ 300
Savings on air conditioning system	- $ 500
Air flow retarder system	+$ 200
No poly vapor barrier	- $ 100
Controlled ventilation system	+$ 150
Basement insulation	+$ 500
Total Incremental Cost	$ 0

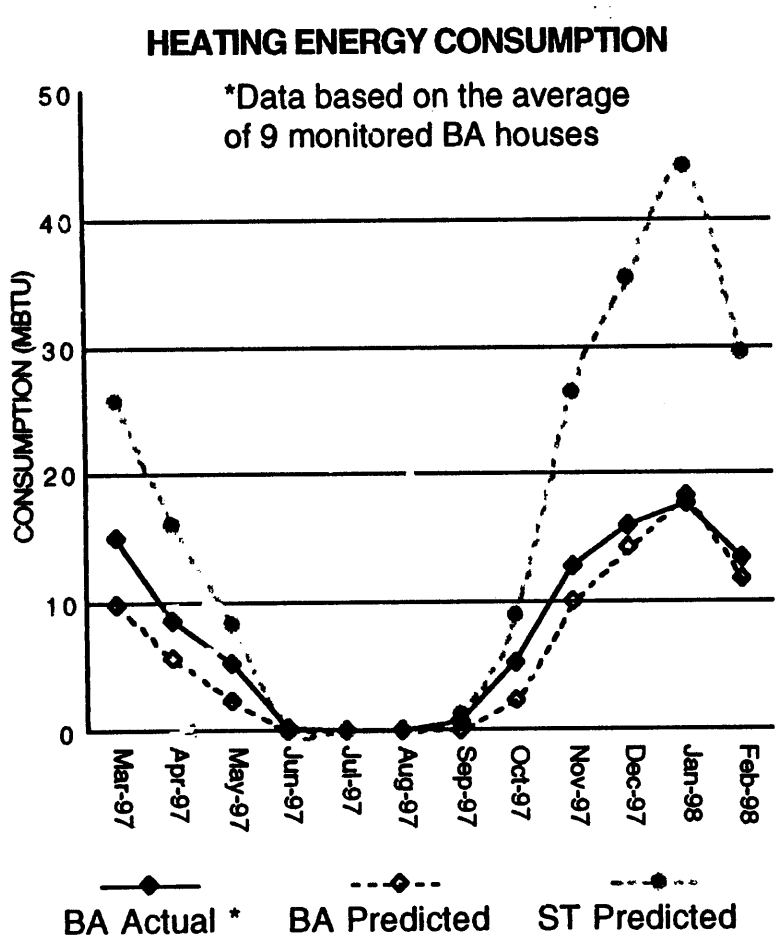
Mixed Climate
Design and Cost Trade-offs

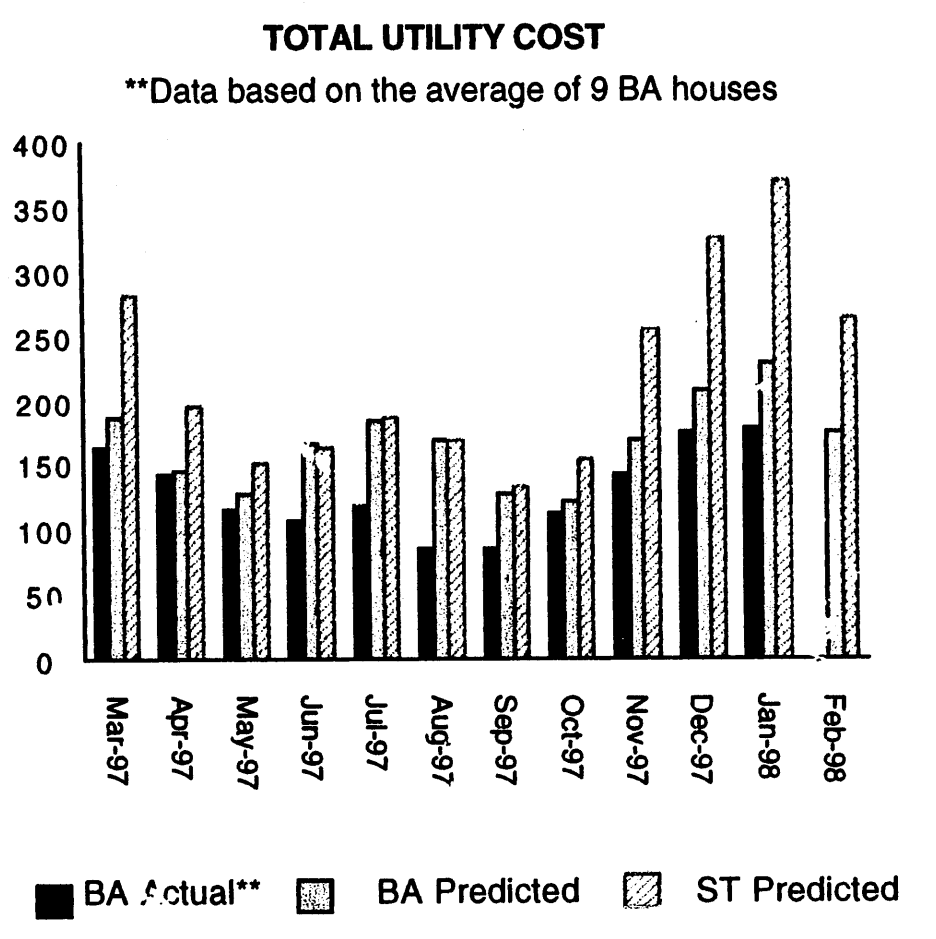
Advanced framing: 2x6s with R-20 instead of 2x4s with R-11	- $ 250
Insulating sheathing	+$ 300
No housewrap	- $ 300
High performance windows	+$ 300
Savings on duct system	- $ 300
Savings on air conditioning system	- $ 500
Air flow retarder system	+$ 200
Controlled ventilation system	+$ 100
Integrated heating DHW system in place of furnace	- $ 100
Total Incremental Cost	-$ 550

Hot Climate
Design and Cost Trade-offs

Not installing roof vents	- $ 250
Installing insulation at underside of roof deck	+$ 750
High performance windows	+$ 500
Savings on air conditioning system	-$1000
Controlled ventilation system	+$ 100
Integrated heating DHW system in place of furnace	- $ 100
Total Incremental Cost	$ 0

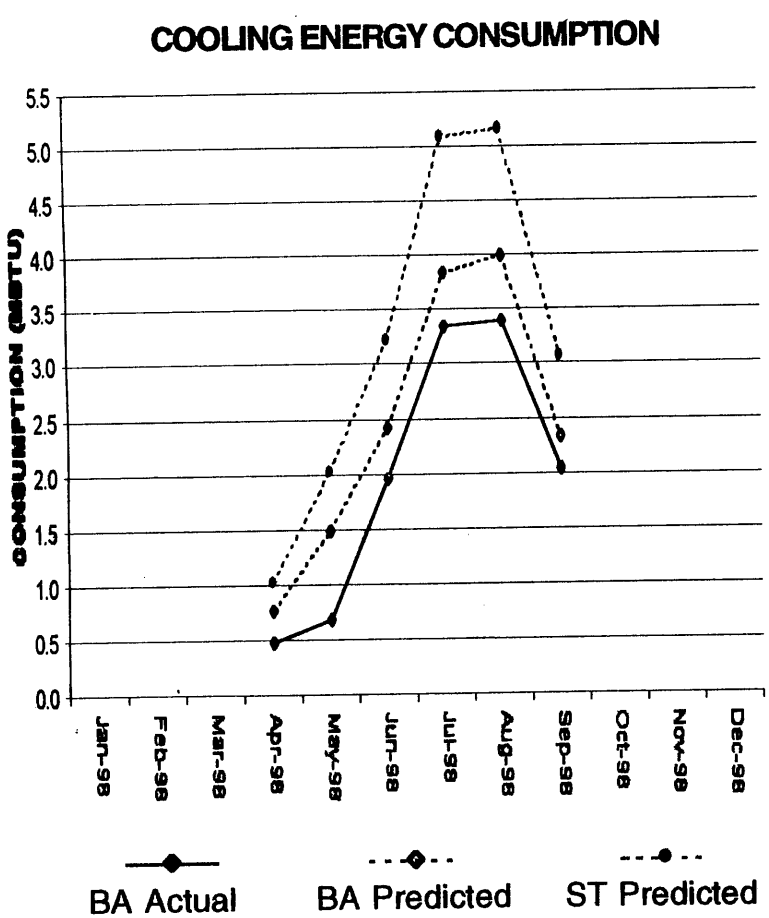
Measured Results from Reengineered Cold Climate Houses

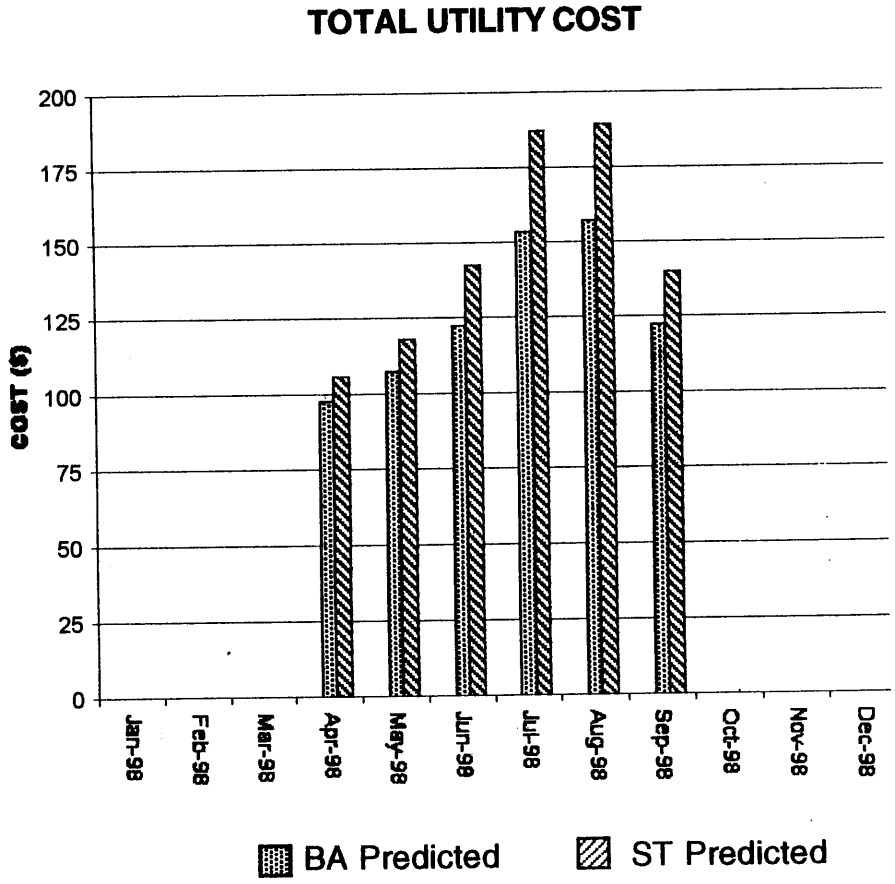




	BA Actual**	BA Predicted	ST Predicted
Yearly Totals	$1558.46**	$2005.09	$2652.84

Measured Results from Reengineered Hot Climate Houses





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Specific Target Performance Metrics

- Overall energy consumption for heating, cooling and water heating should meet Energy Star requirements (30% improvement over a standard reference home based on the envelope and equipment requirements of the 1993 Model Energy Code) as determined by an accredited home energy rating system procedure.
- Air leakage (determined by pressurization testing) should be less than 2.5 square inches/100 square feet leakage ratio (CGSB, calculated at a 10 Pa pressure differential); or 1.25 square inches/100 square feet leakage ratio (ASTM, calculated at a 4 Pa pressure differential); or 0.25 cfm/square foot of building envelope surface area at a 50 Pascal air pressure differential.
- Ductwork leakage to the exterior for ducts distributing conditioned air will be limited to 5.0 percent of the total air handling system rated air flow at high speed determined by pressurization testing at 25 Pa.
- Controlled mechanical ventilation at a minimum base rate of 20 cfm per master bedroom and 10 cfm for each additional bedroom will be provided when the building is occupied. A capability for intermittent base rate ventilation of 0.05 cfm per square foot of conditioned areas will also be provided. Intermittent spot ventilation of 100 cfm will be provided for each kitchen. Intermittent spot ventilation of 50 cfm or continuous ventilation of 20 cfm when the building is occupied will be provided for each washroom/bathroom. Positive indication of shutdown or improper system operation for the base rate ventilation will be provided to occupants.
- Mechanical ventilation system airflow will be tested during commissioning of the building.

continued

Building AMERICA

Specific Target Performance Metrics (continued)

- Mechanical ventilation shall use less than 0.5 watt/cfm for ventilation systems without heat recovery or less than 1.0 watt/cfm for ventilation systems with heat recovery.
- Heat recovery on controlled mechanical ventilation is recommenced in severe heating climate zones. Heat recovery rates of heat recovery ventilators should be greater than 65 percent, including effectiveness of distribution.
- Total ductwork leakage should be limited to 10.0 percent of the total air handling system rated air flow at high speed determined by pressurization testing at 25 Pa.
- Only sealed combustion or power vented direct combustion appliances will be installed in occupied spaces. These appliances will be rated to vent properly at largest expected negative pressure. Gas cooktops and gas ovens should only be installed in conjunction with exhaust fans.
- Major appliances will meet high energy efficiency standards using current appliance ratings. Only those appliances in the top one-third of the DOE Energy Guide rating scale will be selected.
- Lighting power density will not exceed 1.0 Watts per square foot.
- Systems that provide control over space conditioning, hot water or lighting energy use should be clearly marked. Information relating to the operation and maintenance of such systems should be provided.
- The designer and general contractor should provide comprehensive information to occupants relating to the safe, healthy, comfortable operation of the building and mechanical systems.

Building AMERICA

- BSC has developed quickly measurable performance metrics that allow the prediction and quantification of building performance
- BSC has developed construction techniques, equipment and systems that allow production home builders to meet the performance metrics with no incremental cost
- When homes are constructed meeting the performance metrics, typical heating energy consumption is approximately 50% less than typical code construction and cooling energy consumption is approximately 30% less than typical code construction

Building AMERICA

- Homes built meeting the performance metrics also are in compliance with:
  - ASHRAE Standard 62 — Ventilation for Acceptable Indoor Air Quality
  - ASHRAE Standard 55 — Thermal Comfort
  - ASHRAE Standard 91 — Energy Conservation
  - EPA Energy Star — 30% better than MEC
  - American Lung Association Health House Program
  - New Minnesota Building Code
- Homes built under the program have significantly reduced warranty costs and callbacks. One of our builder members (Town & Country Homes) has reduced warranty claims and callback by approximately $400,000 per year since starting the program in 1995. In 1995, Town & Country Homes reported 92 freezing pipe complaints. Las year they received 3.

Building AMERICA

- Homes built meeting the performance metrics consume cooling energy at approximately 60% of ACCA Manual J. New systems under the Building America program are sized to 80% of ACCA Manual J. Typical standard practice systems are installed at 150% to 200% of ACCA Manual J. The cost and energy savings associated with this approach are enormous and represent the single greatest achievement of this program.

- Oversizing of ACCA Manual J is pervasive in the industry due to compensation for duct leakage the exterior and inappropriate refrigerant charge. BSC has eliminated duct leakage with innovative building envelope design and has implemented the CHECKME field computer-based refrigerant charge quality control program thereby allowing equipment to be sized at 80% of ACCA Manual J.

Building AMERICA

- BSC has developed innovative building envelope designs for hot-dry and hot-humid climates that allow ductwork and air handlers to be located within the conditioned space/building pressure boundary
- The unvented roof designs developed under the program lead to subsequent innovations in roof insulation systems (GreenStone's COCOON) and building code changes
- The unvented roof designs developed for hot-humid climates significantly reduce latent loads (moisture) and allow the use of simple off-the-shelf components to provide controlled ventilation with dehumidification

Building AMERICA

- Innovative air distribution systems have been developed that address the problems of interstitial pressurization/depressurization and intra-zone air pressure imbalances
- These innovative air distribution systems work better and cost less than typical conventional standard practice

Building AMERICA

- Climate specific controlled ventilation strategies have been developed that address the problems associated with humidity control in the humid south and pressurization in the north
- The strategies are a model/blueprint for implementing ASHRAE Standard 62.2 — Ventilation for Indoor Air Quality in Residential Buildings

Building AMERICA

- Many advanced framing details and techniques have been developed over the past 30 years. Despite the long history of innovation advanced framing has not been adopted by either production builders or others. BSC believes the reason has been due to a lack of systems integration and code resistance.

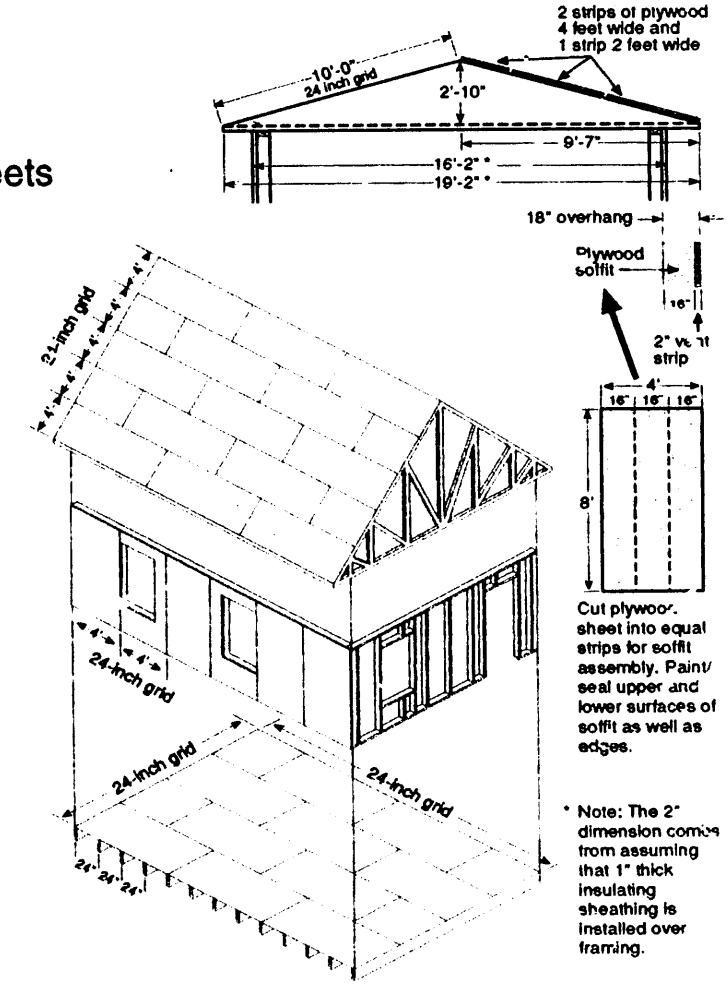
- BSC integrated advanced framing into complete building envelope design and mechanical system layout. Modular dimensioning, detailed construction drawings and structural mock-up testing were used to develop updated approaches to advanced framing.

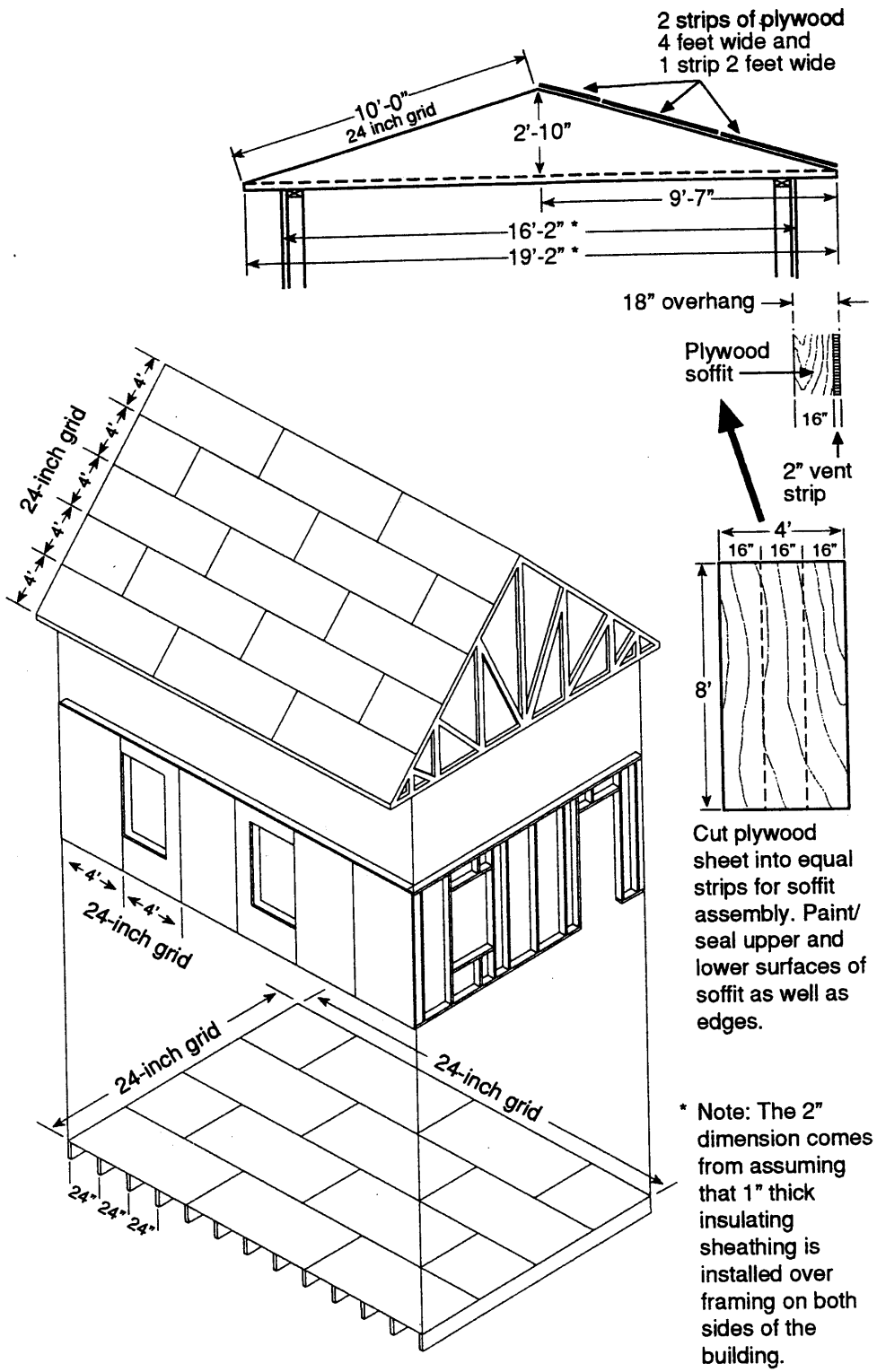
- Working with CERL (the US Army research laboratory), BSC is facilitating code approval of advanced framing techniques by the city of Los Angeles. Full scale assemblies are being tested under the new dynamic seismic loading protocols developed after the Northridge earthquake.

Advanced Framing System

Schematic Dimensions

- Plywood, OSB and sheathings all come in 4'x8' sheets
- Design out-to-out dimensions on 2' increments
- Reduce sheet good waste

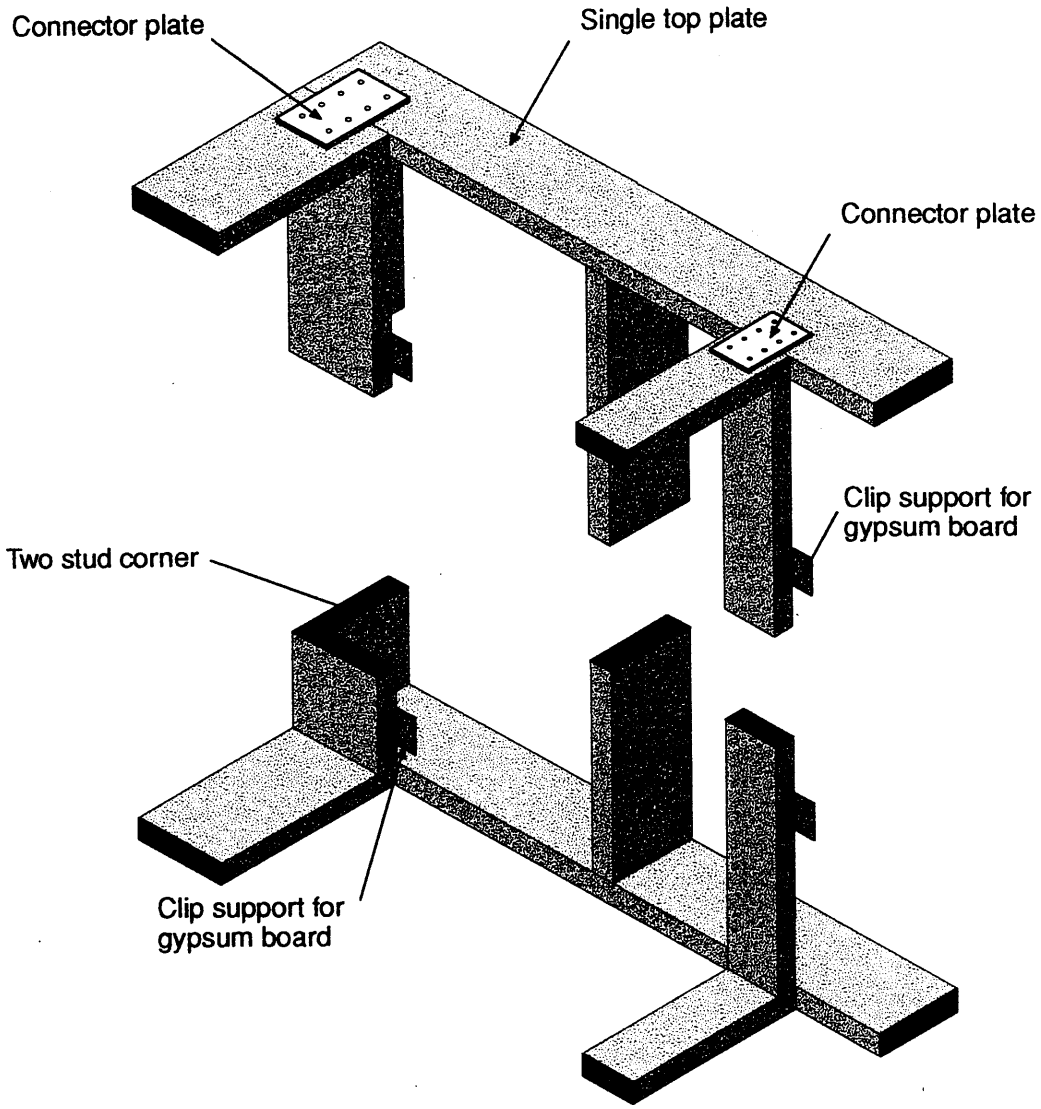




Cut plywood sheet into equal strips for soffit assembly. Paint/ seal upper and lower surfaces of soffit as well as edges.

* Note: The 2" dimension comes from assuming that 1" thick insulating sheathing is installed over framing on both sides of the building.

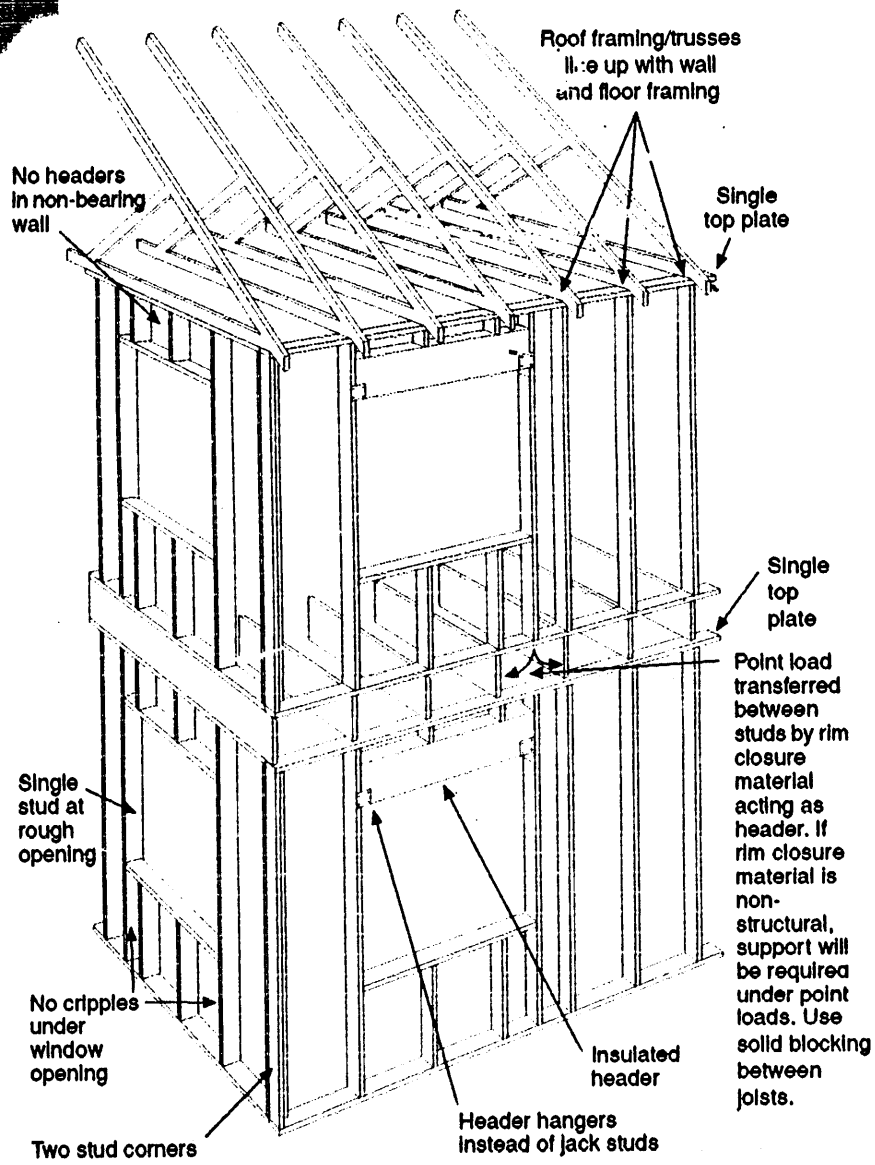
Efficient Material Use by Design



Corner and Interior Partition Wall Framing

Build
AMERICA

ack Framing



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ENERGY EFFICIENCY AND RENEWABLE ENERGY • U.S. DEPARTMENT OF ENERGY

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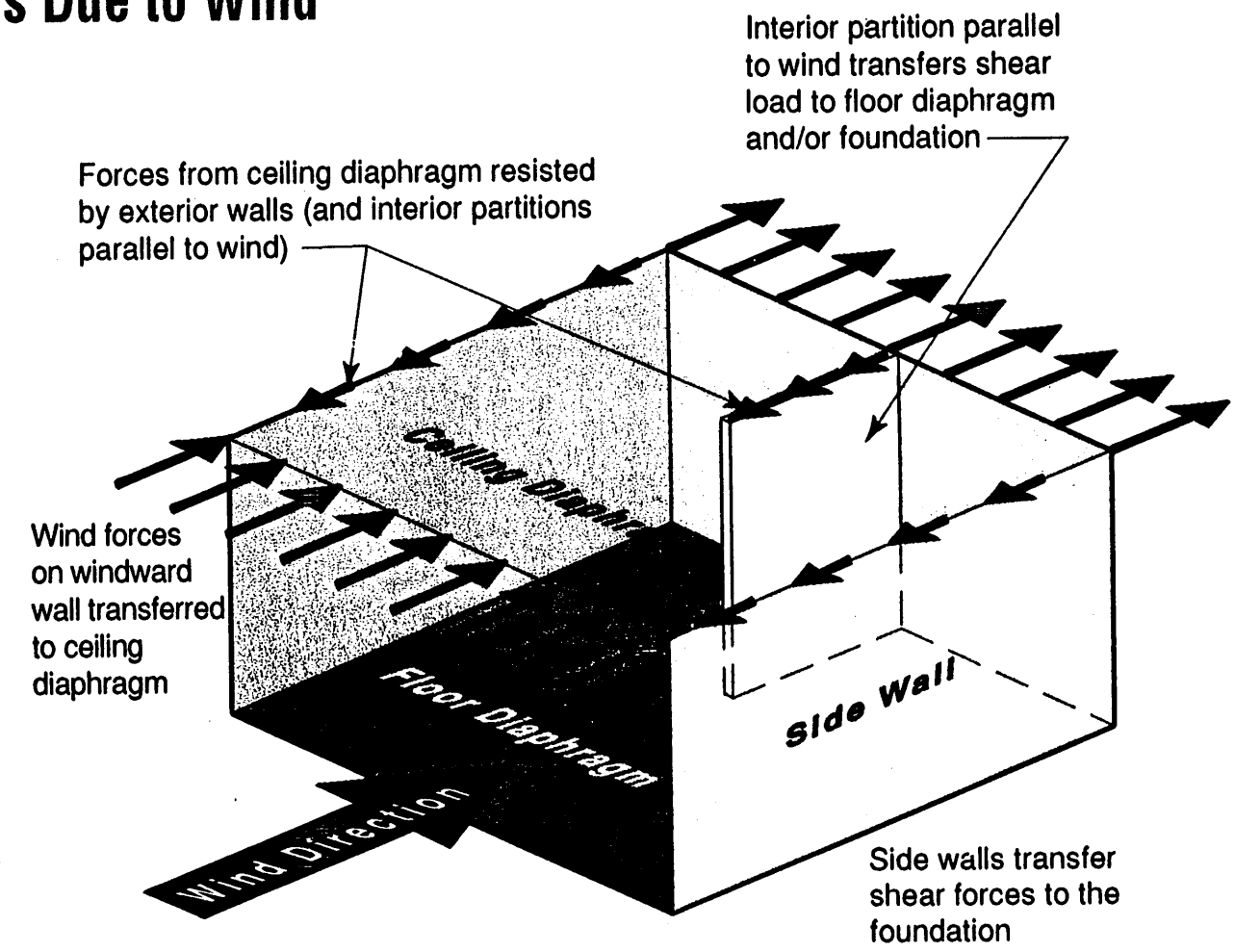
Shear Forces Due to Wind



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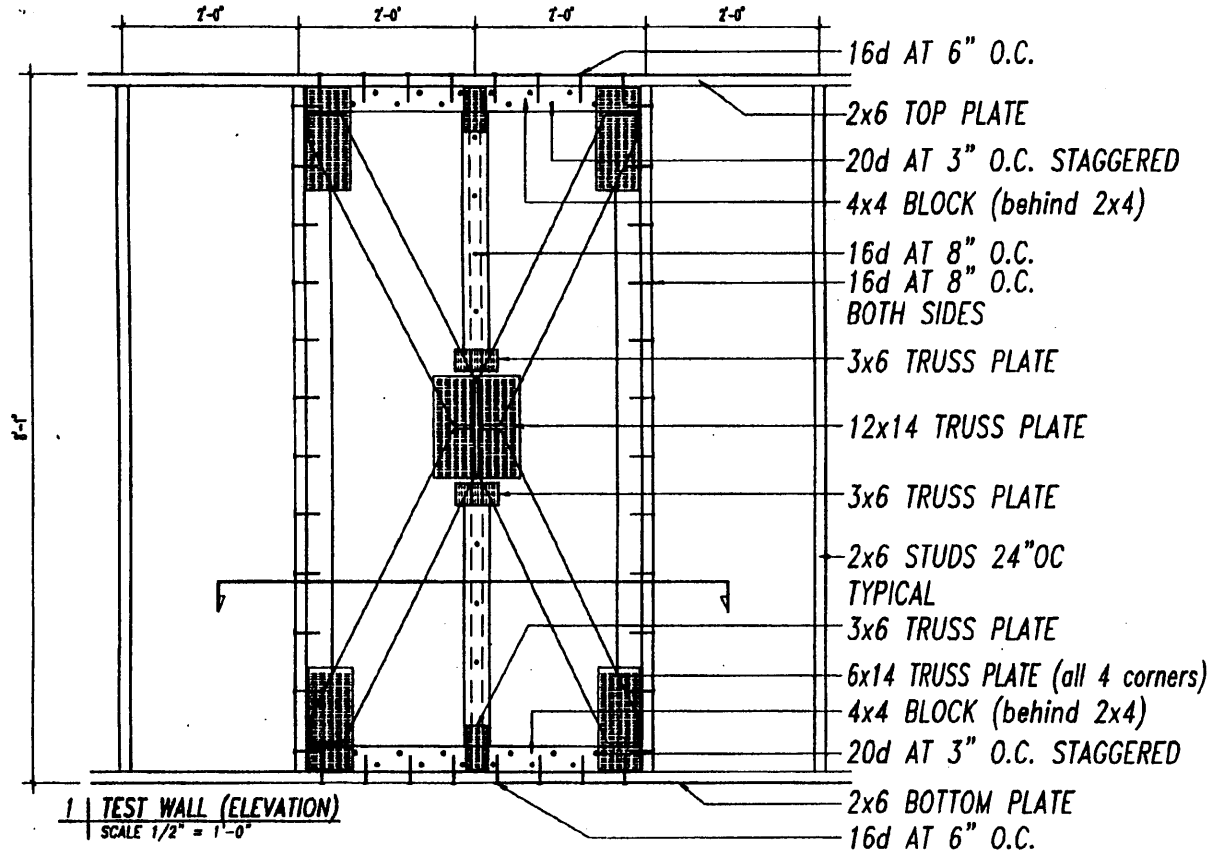
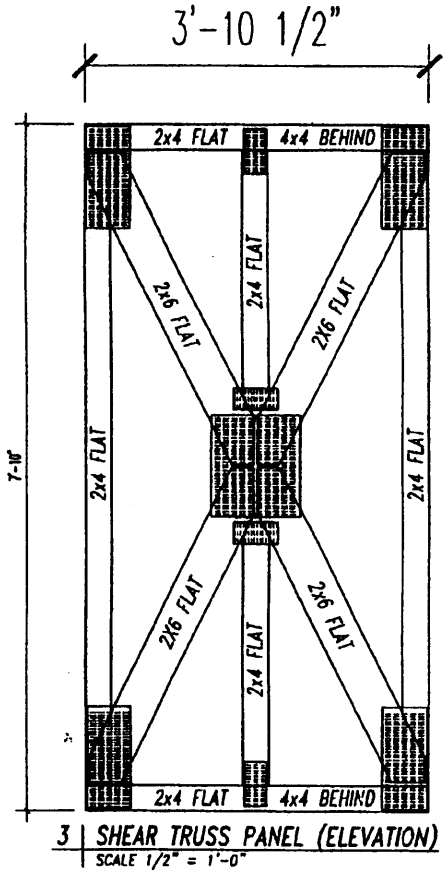
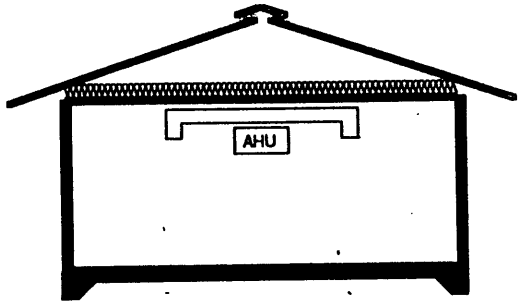
Shear Panel



1 | TEST WALL (ELEVATION)
SCALE 1/2" = 1'-0"



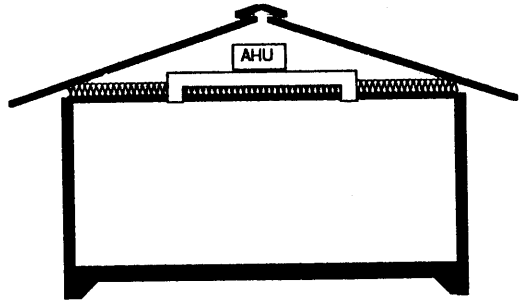
3 | SHEAR TRUSS PANEL (ELEVATION)
SCALE 1/2" = 1'-0"



House 1 (Base Case)

Fully Ventilated Attic
No Ductwork in Attic
Perfect Air Barrier at Ceiling

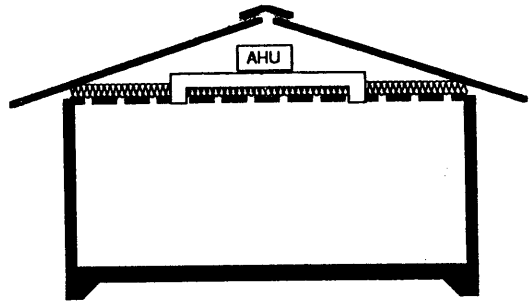
AHU and ductwork completely inside the conditioned space



House 2

Fully Ventilated Attic
Perfectly Sealed Ductwork and AHU in Attic
Perfect Air Barrier at Ceiling

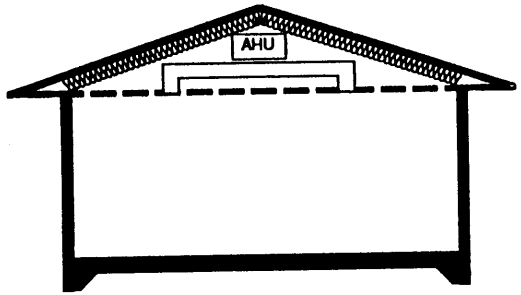
Energy performance -5% to -7% penalty compared with base case due to conductive losses across the ductwork and AHU



House 3

Fully Ventilated Attic
Leaky Ductwork and AHU in Attic
Imperfect Air Barrier at Ceiling

Energy performance -15% to -30% penalty compared with base case due to air change induced by leaky ductwork. House 3 is the true "Base Case" for typical residential construction



House 4 **Cost = -$300 compared with House 3**

Non-Ventilated Attic
Insulation Tight to Underside of Roof Deck
Leaky Ductwork and AHU completely inside the Conditioned Attic
Typical Ceiling Construction

Energy performance -3% to -5% penalty compared with base case (House 1). However, it allows for 15% to 25% savings over the true base case (House 3)

Comparison of Energy Performance of Vented vs. Unvented Roofs in Las Vegas

Building Science Corporation

In cooperation with

Pulte Homes Corporation in Las Vegas

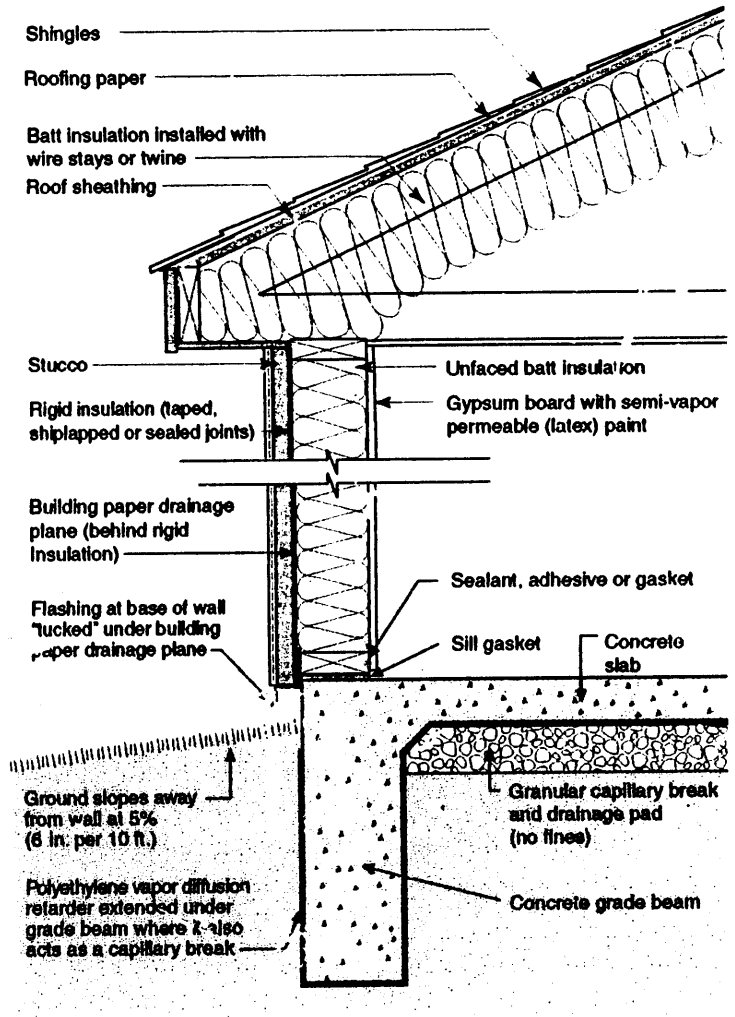
In the US DOE sponsored

Building America program

Field support provided by the National Renewable Energy Laboratory

Air Barrier System

Exterior Air Flow Retarder Using Exterior Sheathing, Stucco and Roof Deck



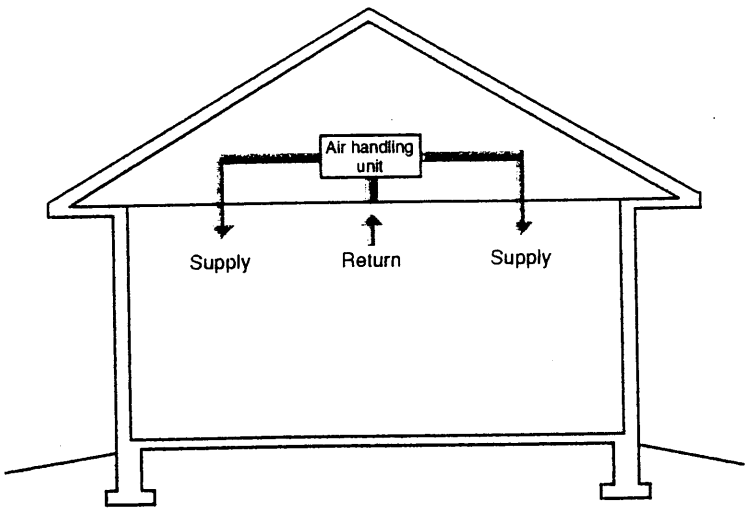
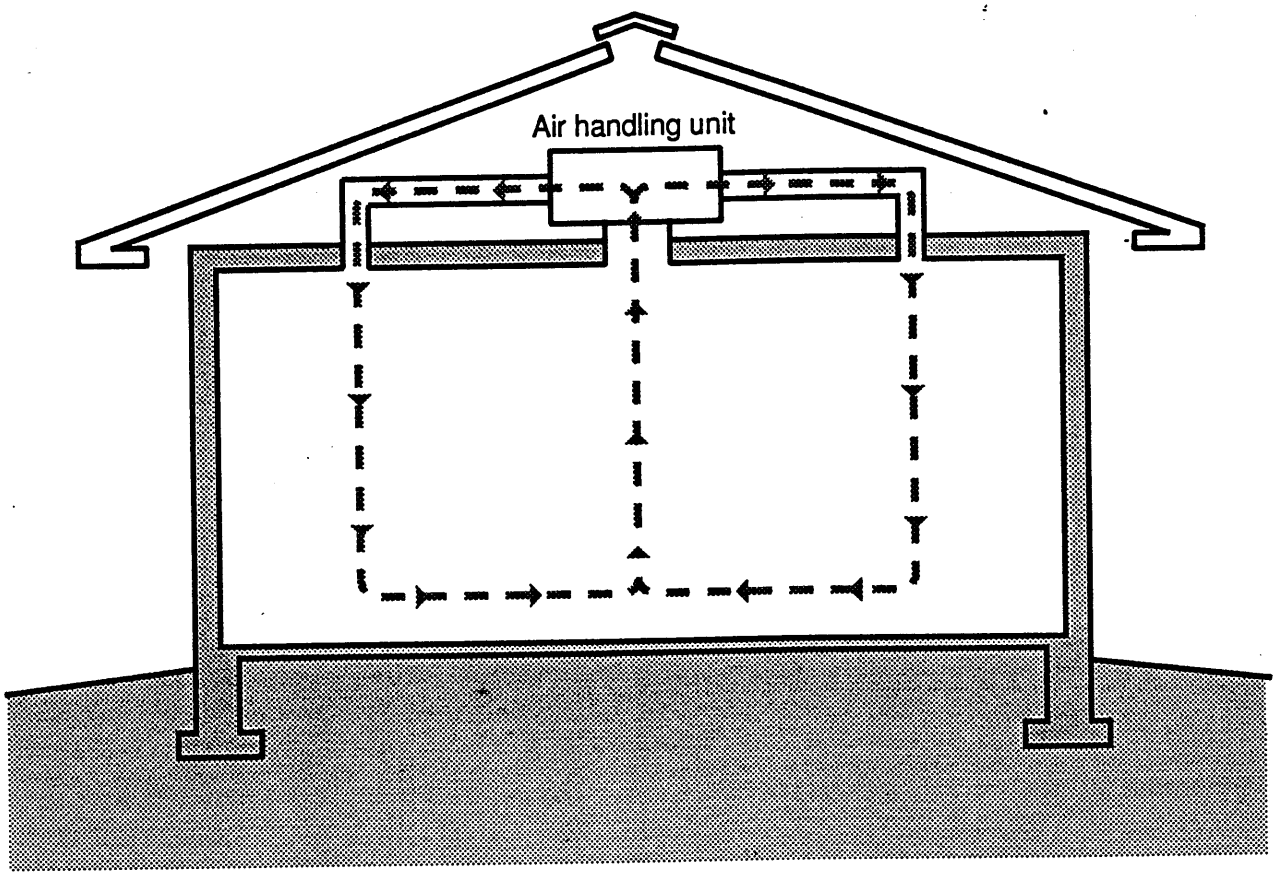


Figure 5.22

Unvented, Conditioned Attic

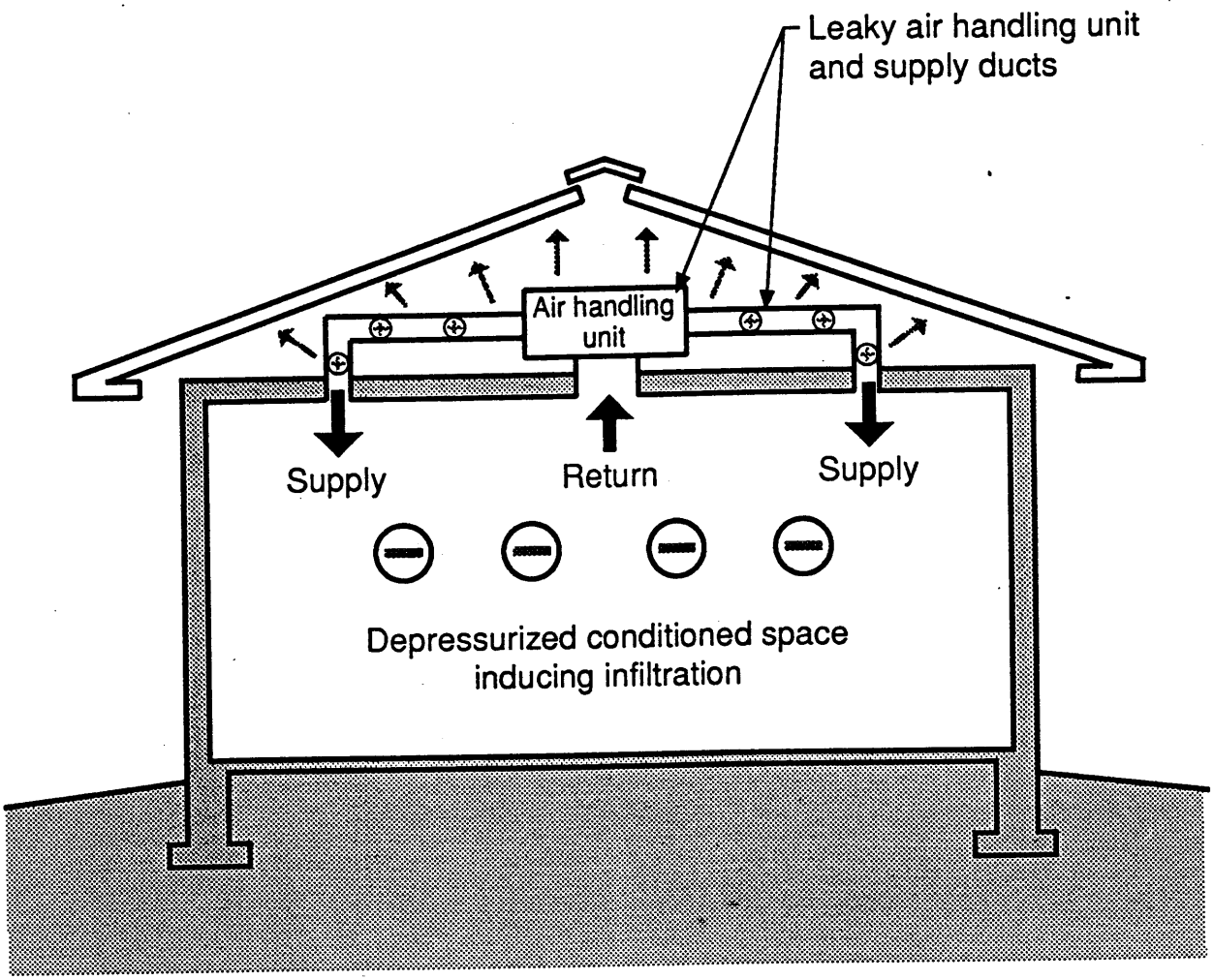
- The air handling unit is located in an unvented, conditioned attic
- The attic insulation is located at the roof deck



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Ductwork and Air Handlers in Vented Attics

- **No air pressure differences result in a house with an air handler and ductwork located in a vented attic if there are no leaks in the supply ducts, the return ducts or the air handler and if the amount of air delivered to each room equals the amount removed**
- **If no air leakage occurs in the ductwork and air handler, locating the ductwork and air handler in a vented attic typically results in an approximate 5% thermal penalty to the overall performance of the building due to conductive gains across the ductwork and air handler when ductwork is insulated to approximately R-6**



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Ductwork and Air Handlers in Vented Attics

- **Supply ductwork and air handler leakage is typically 20% or more of the flow through the system; in a 5 ton A/C system there is approximately 400 cfm of leakage, or almost the equivalent to 1 ton of capacity**
- **Leakage out of the supply system into the vented attic results in an equal quantity of infiltration; in other words, 400 cfm of leakage out of the supply system into the attic results in 400 cfm of infiltration (typically 2/3 or more) through the attic ceiling; this results in 60°F air conditioned air leaving the enclosure**
- **Air leakage in ductwork and air handlers located in vented attics typically results in an approximate 20-to-40% thermal penalty to the overall performance of the building**

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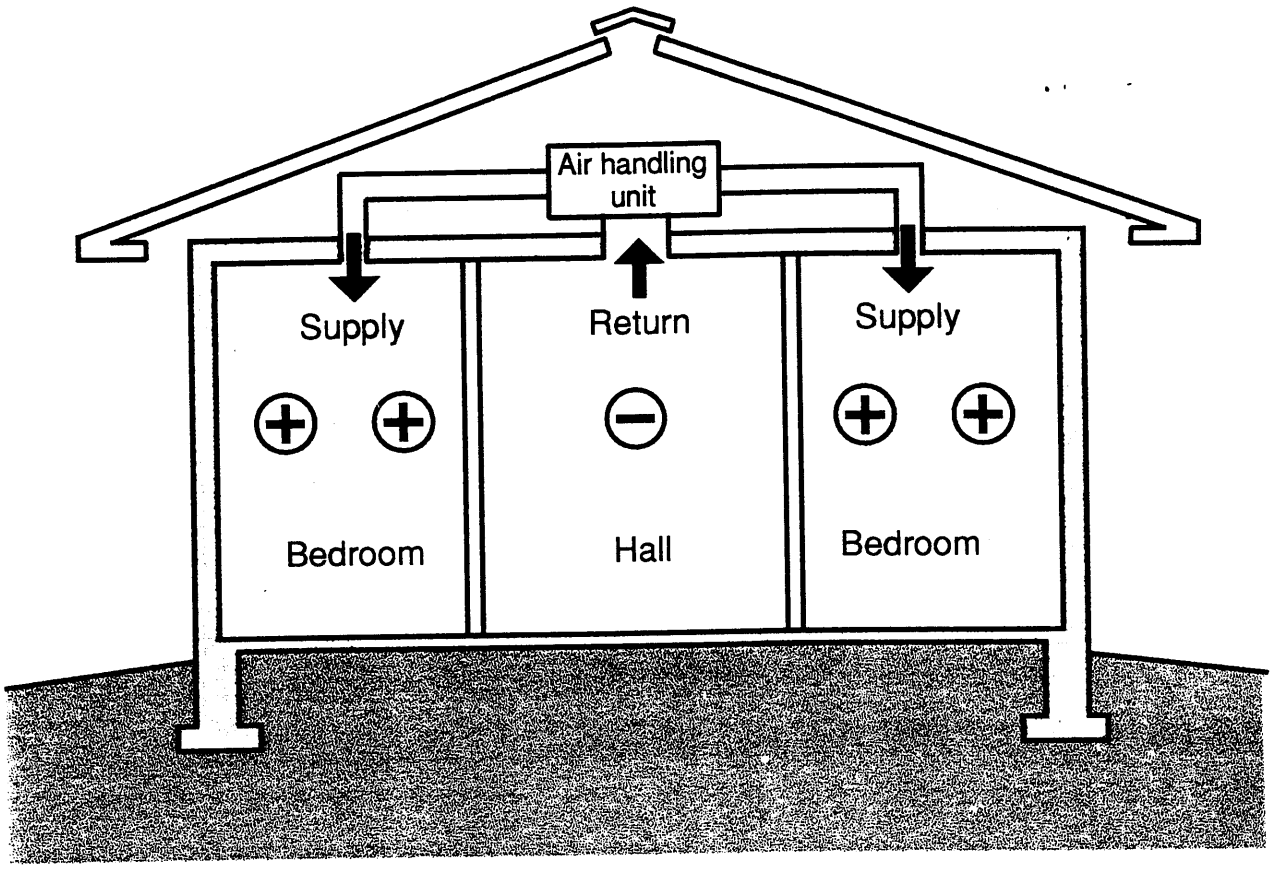
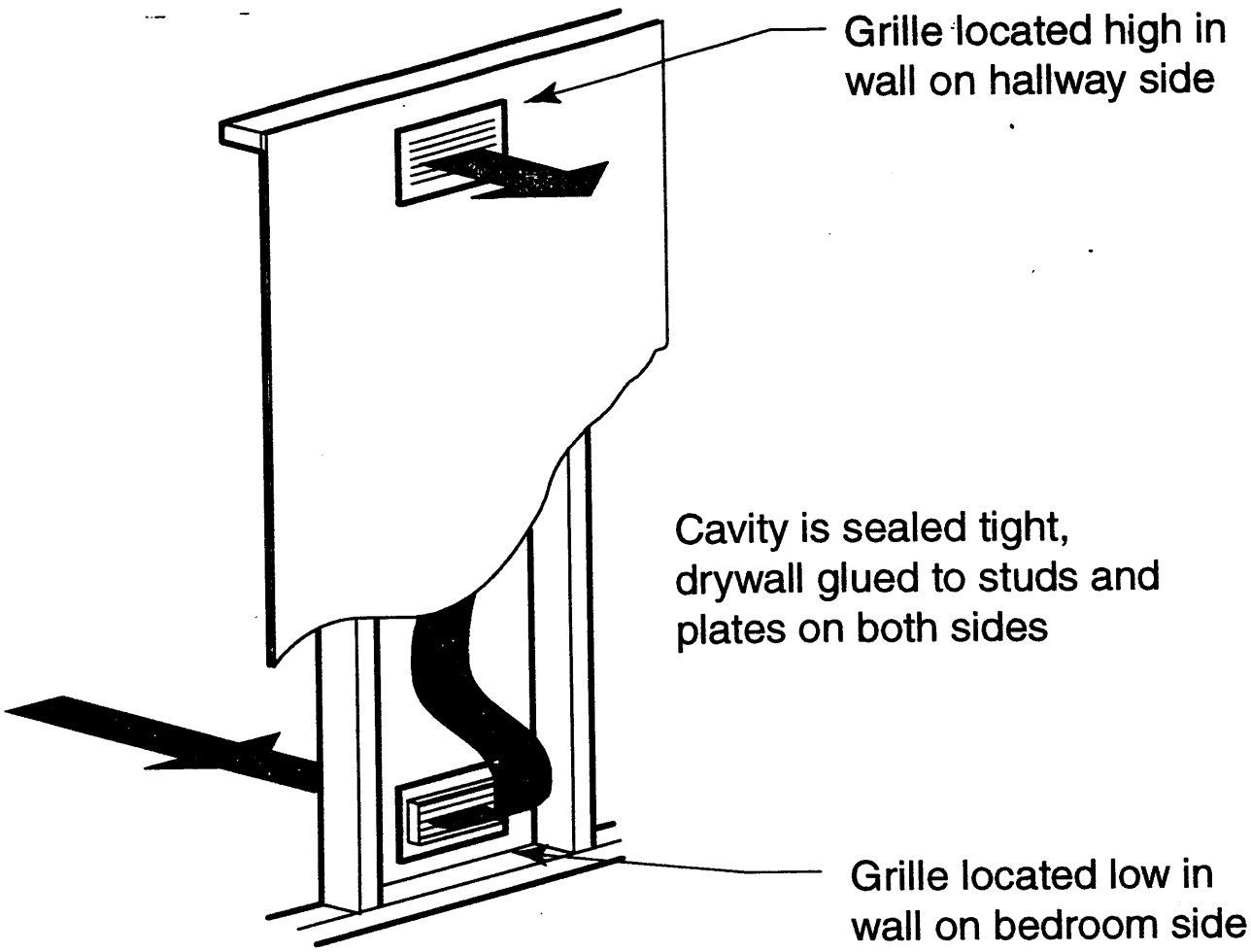


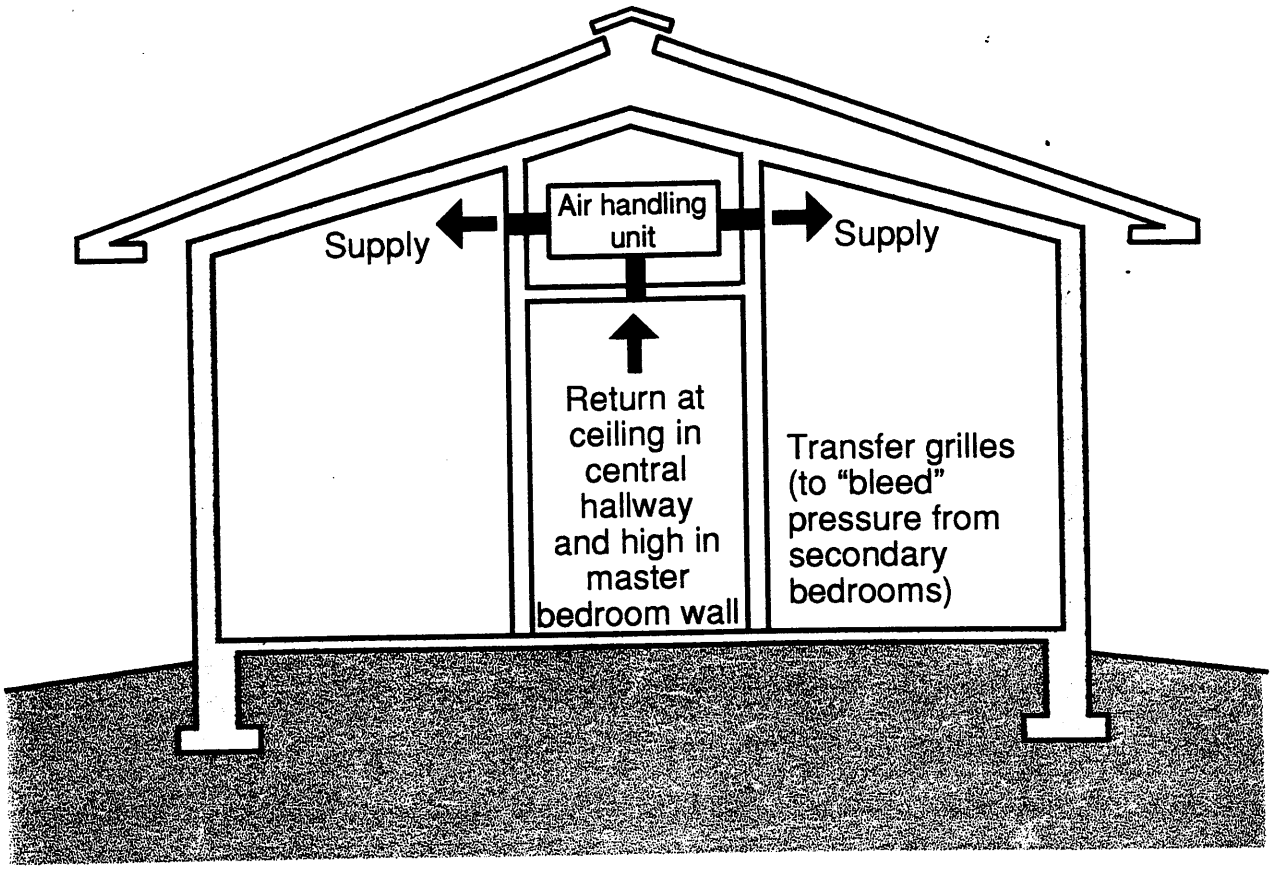
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Insufficient Return Air Paths

- **Pressurization of bedrooms often occurs if insufficient return pathways are provided; undercutting bedroom doors is usually insufficient; transfer grilles, jump ducts or fully ducted returns may be necessary to prevent pressurization of bedrooms**
- **Master bedroom suites are often the most pressurized as they typically receive the most supply air; a fully ducted return in the master bedroom suite is generally recommended**
- **When bedrooms pressurize, common areas depressurize; this can have serious consequences when fireplaces are located in common areas and subsequently backdraft**



Transfer Grille

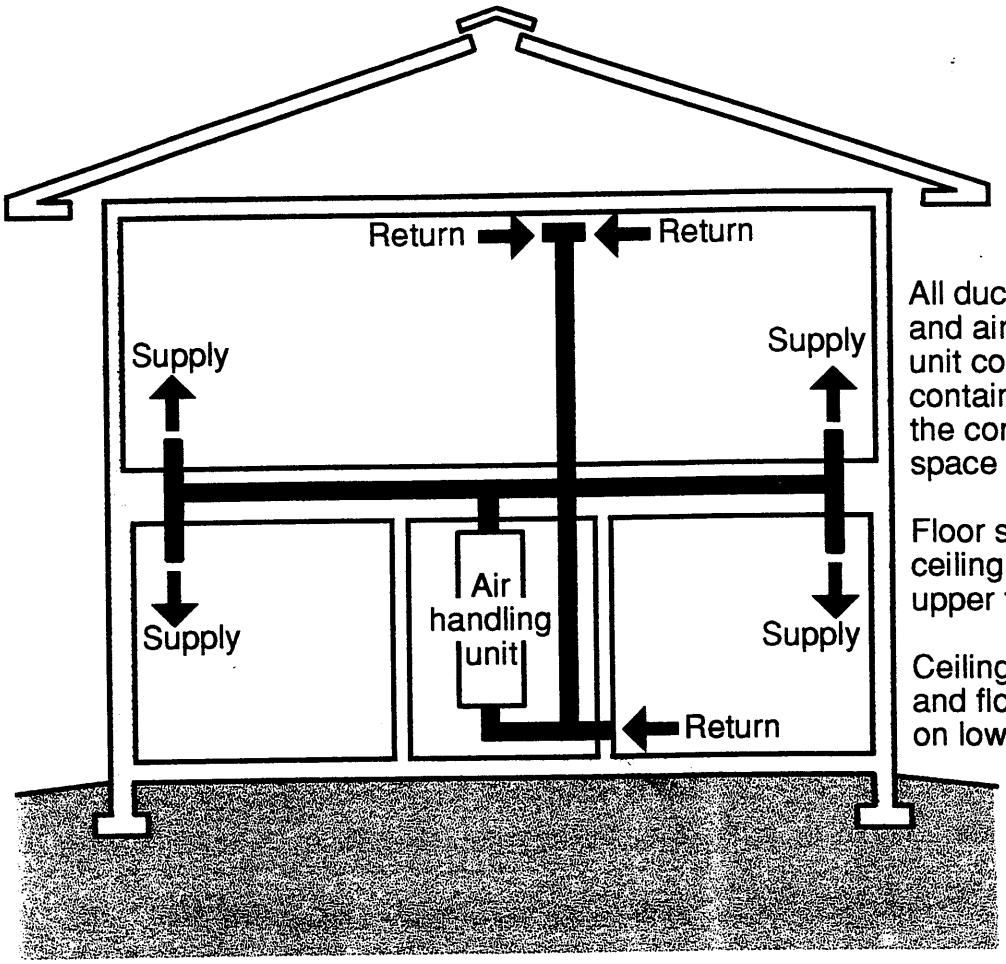


Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Slab-on-Grade Dropped Ceiling Vented Attic

- **The air handling unit is located in an interior closet and the supply and return ductwork is located in a dropped hallway**
- **Transfer grilles bleed pressure from secondary bedrooms**
- **Ductwork does not have to extend to building perimeters when thermally efficient windows and thermally efficient building envelop construction is used; throw-type registers should be selected**
- **Typical low efficiency gas appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pumps, heat pump water heaters or sealed combustion furnaces and water heaters should be used**
- **A hot water-to-air fan-coil in an air handling unit can be used to replace the gas furnace/gas burner. The fan-coil can be connected to a standard gas water heater with a draft hood located in the garage. Alternatively, the gas water heater can be sealed combustion or power vented and located within the conditioned space.**

Building Science Corporation
July, 1998



All ductwork and air handling unit completely contained within the conditioned space

Floor supply and ceiling return on upper floor

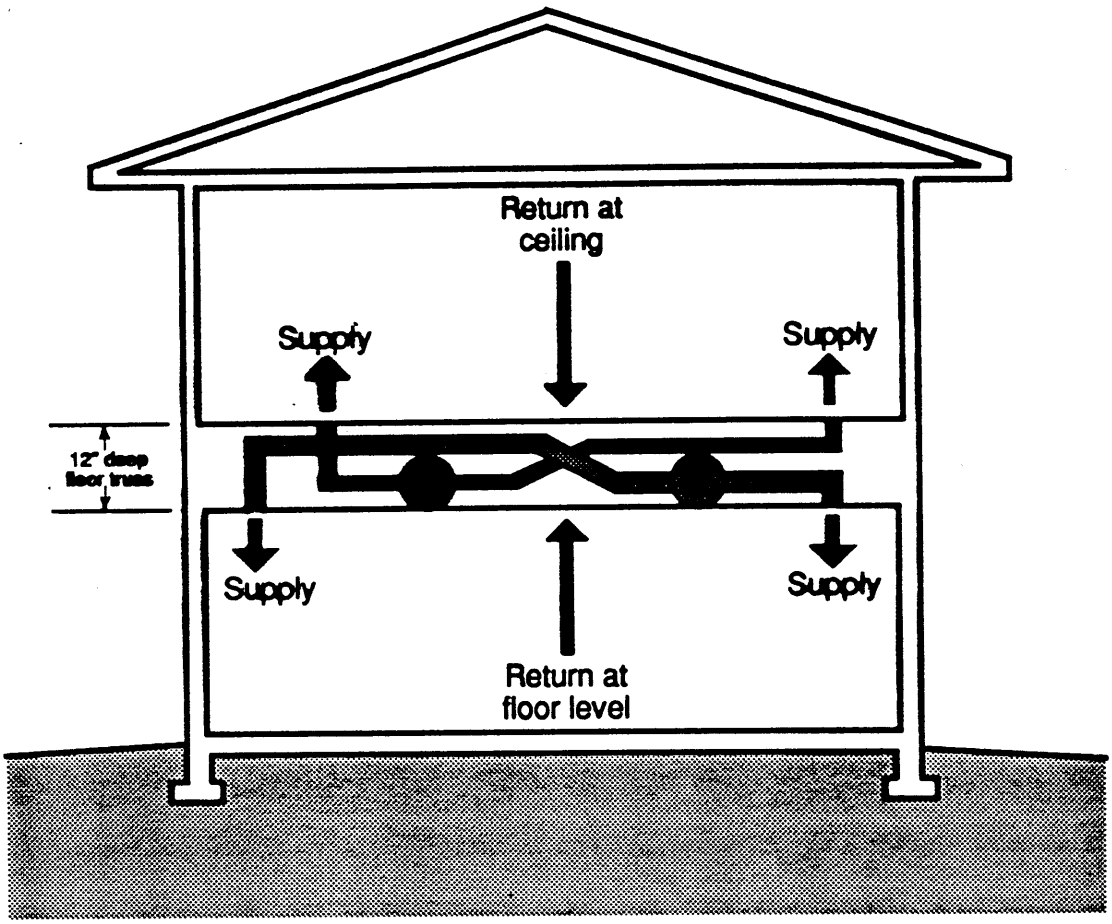
Ceiling supply and floor return on lower floor

Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Slab-on-Grade
Vented Attic

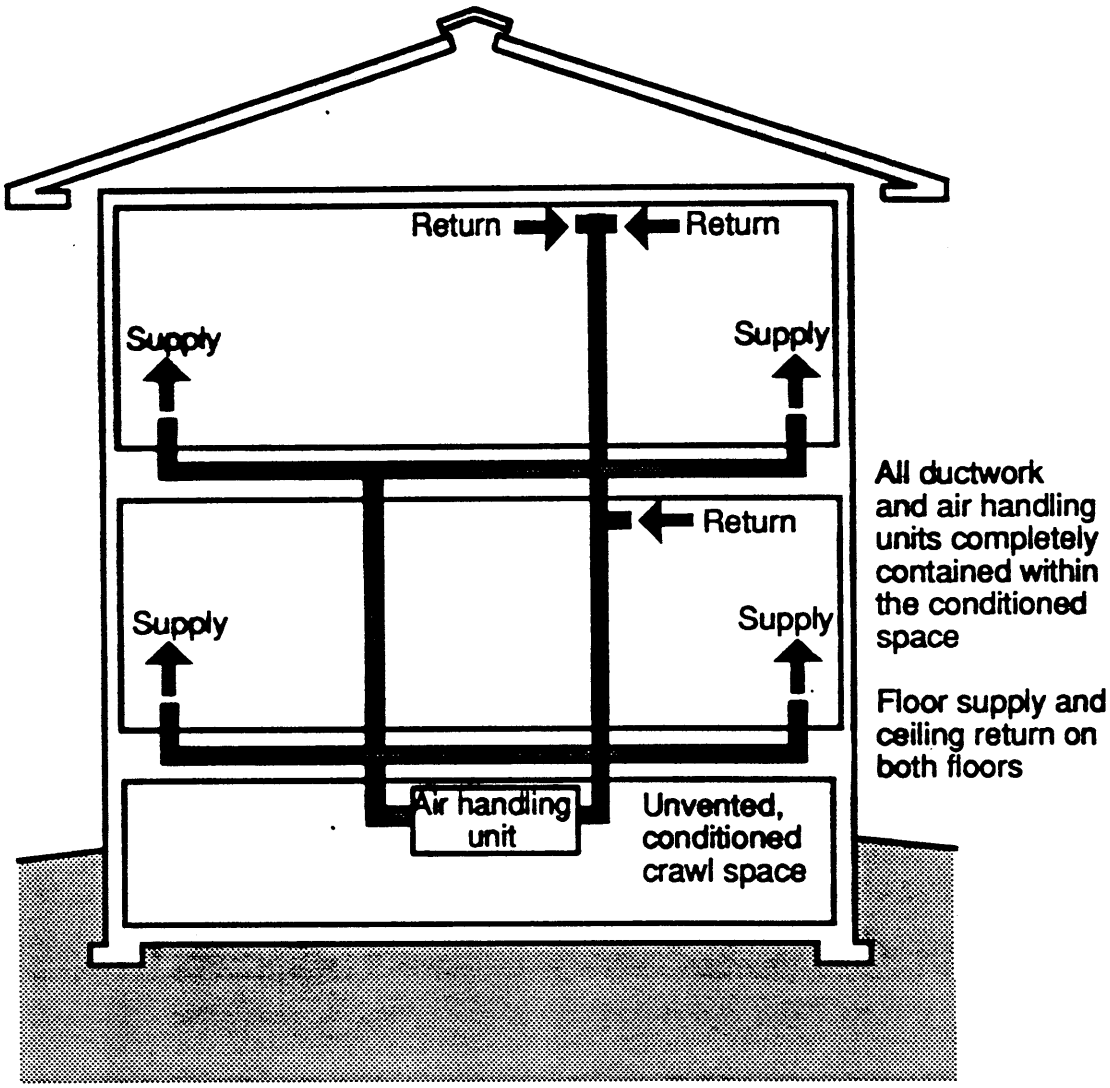
- **The air handling unit is located in an interior closet/utility room**
- **Typical low efficiency gas appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pumps, heat pump water heaters or sealed combustion furnaces and water heaters should be used**
- **A hot water-to-air fan-coil in an air handling unit can be used to replace the gas furnace/gas burner. The fan-coil can be connected to a standard gas water heater with a draft hood located in the garage. Alternatively, the gas water heater can be sealed combustion or power vented and located within the conditioned space**

Building Science Corporation
July, 1998



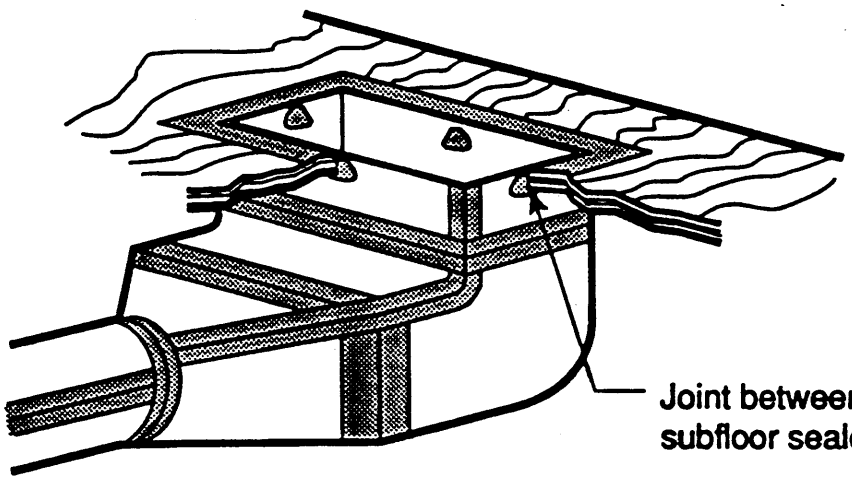
Floor Truss Supply Duct System

- A 6" diameter flex duct can cross over an 8" diameter flex-duct within a 12" deep floor cavity. At the point of crossing both ducts assume an oval cross section without a resultant meaningful/significant pressure drop.
- Flows between first and second floor can be balanced
- A return is located at the top of the second floor at the ceiling level
- A return is also located at the first floor at the floor level
- Transfer grilles are installed between bedrooms and hallways
- Air handler can be located in dropped ceiling below second floor framing

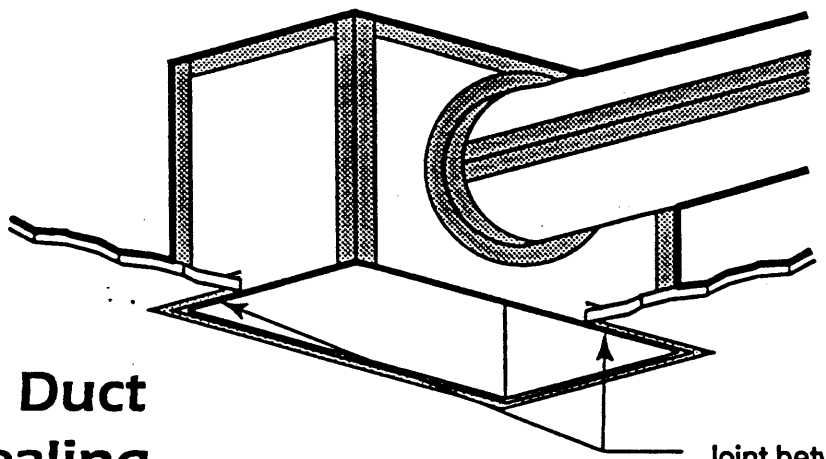


Unvented, Conditioned Crawl Space
Vented Attic

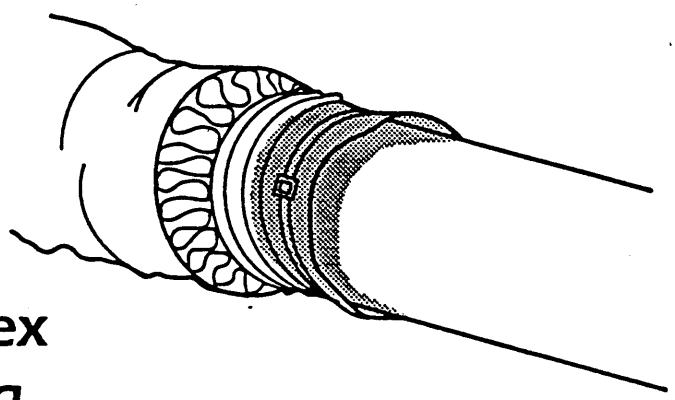
- The air handling unit is located in an unvented, conditioned crawl space. The crawl space has a supply duct, but no return. A transfer grille is provided through the main floor to retrun air to the common area of the house and subsequently to the return grille on the main floor.
- A hot water-to-air fan-coil in an air handling unit can be used to replace the gas furnace/gas burner. The fan-coil can be connected to a standard gas water heater with a draft hood located in the garage. Alternatively, the gas water heater can be sealed combustion (or power vented) and located within the conditioned space.



Floor Boot Air Sealing

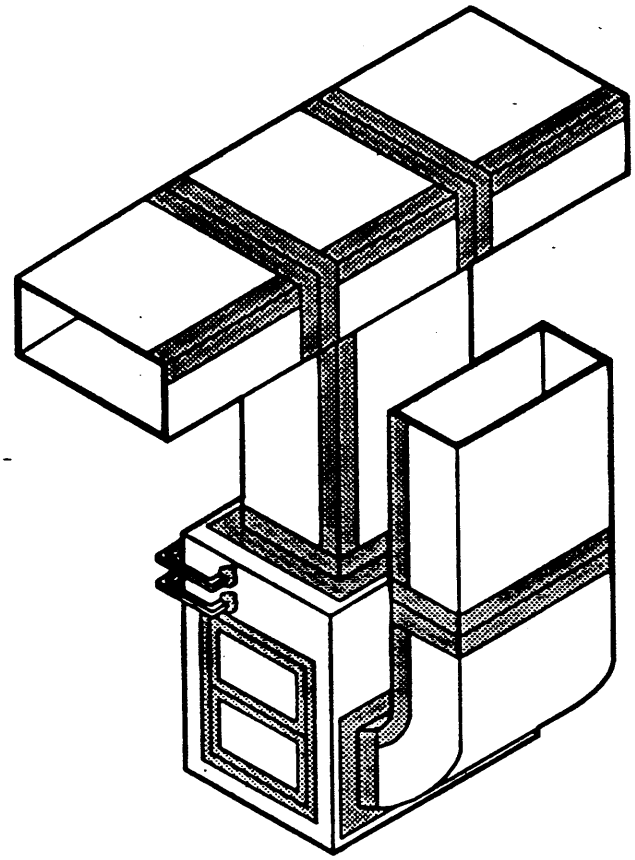


Rigid Duct Air Sealing

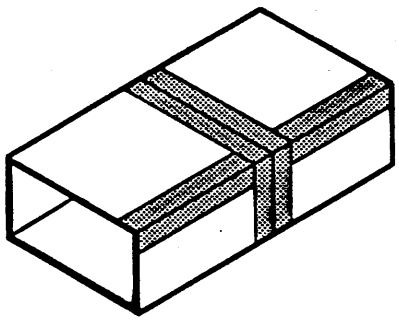


Rigid to Flex Air Sealing

Air Handler
Air Sealing



Rigid Duct
Air Sealing



Flex Take-off
from Rigid
Air Sealing